ATMOSPHERIC NITROGEN AS PLANT-FOOD.

FARMERS in all older portions of the country buy large quantities of nitrogen in artificial fertilizers. Nitrate of soda, sulphate of ammonia, dried blood, cottonseed-meal, and fish-scraps owe their fertilizing value mainly, and Peruvian guano and tankage largely, to nitrogen; and the same element is one of the chief ingredients of bone manures, ammoniated phosphates, and many other fertilizers. According to an estimate by the Connecticut Experiment Station, not less than five hundred thousand dollars are expended annually for commercial fertilizers in Connecticut. A large amount of this goes for nitrogen, which is one of the dearest of the ingredients of fertilizers, and costs at retail from eight or ten to eighteen cents or more a pound.

The Storrs School Agricultural Experiment Station, Mansfield, Conn., in its October bulletin, reports a continuation of an investigation of atmospheric nitrogen as plant-food, begun some years ago at Wesleyan University, Middletown, where the chemical work of the station has been carried on since the establishment of the latter in 1888. The details of the experiments there reported were conducted by Mr. C. D. Woods, formerly assistant in chemistry in Wesleyan University, and now chemist of the station.

The quantities of nitrogen in ordinary crops, and the cost of the same in the better commercial fertilizers, vary from 31.5 pounds for potatoes, to 80.3 pounds for clover-hay, costing from $4.73 to $12.05.

The plants must have this nitrogen, or they cannot grow. They obtain part of it from the soil, and the rest from the air. The nitrogen of the soil has either been accumulated in the past or is supplied in manures. A small quantity, in the form of ammonia and other compounds of nitrogen, is continually brought to the soil by rain or snow. Late research implies that soils acquire nitrogen from the air by the aid of microbes or electricity, or probably both. The nitrogen in the soil is being continually leached away by drainage-waters, and more or less of it escapes into the air. Soils which are not cultivated, and from which the produce is not removed, accumulate more nitrogen than they lose, so that many virgin soils have a large stock. By ordinary cultivation and cropping, the nitrogen is gradually exhausted, unless it is returned by manures or otherwise.

The main questions have been, first, Can plants make use of atmospheric nitrogen to any considerable extent? second, If they do, is it the free nitrogen of the air that they acquire? There are certain kinds of plants, like clover, beans, and others belonging to the family of the legumes or *Papilionaceæ*, which generally get on very well without nitrogenous fertilizers in worn-out soils; and it would seem as though these plants, at any rate, must in some way be able to make use of the nitrogen of the air. But the classic experiments of Boussingault in France, of Lawes and Gilbert in England, and others, have been widely accepted as proving that plants cannot use the free nitrogen of the air, and that they get practically very little combined nitrogen from the air, so that they are dependent upon that previously stored in the soil or supplied in manures. Still many experimenters have not regarded the question as definitely settled.

While the experiments of Boussingault, and Lawes and Gilbert, differ in their details, they agree in this, that the plants were under conditions widely different from those in ordinary culture. The especial object was to find whether plants acquire free nitrogen; and the plants were for the most part grown under cover, to exclude combined nitrogen, and in artificial soil containing little or no nitrogen. The growth was generally stunted and abnormal.

Later experiments on more or less similar plans have brought similar results. Investigations by Ville in France, however, implied that plants can acquire nitrogen from the air, but his conclusions were not generally accepted.

Some years ago a series of experiments was conducted by Mr. C. D. Woods, in which the conditions were more like those in which plants commonly grow. The method used was that of sand-culture. By proper management, feeding, and watering, plants may be grown as large, as healthy, and in every way as well developed, in pure sand as in the richest soil. For these experiments sea-sand was used. To remove all traces of material containing nitrogen (except, of course, air), the sand was carefully sifted, then washed, and finally heated in iron pots in a furnace, so hot that the pots nearly melted. It was then put in glass jars, and water was added in which were dissolved salts containing the mineral elements of plant-food, potash, lime, iron, sulphuric acid, phosphoric acid, etc., and in some cases nitrogen in the form of nitrate of potash or lime. The seeds were then sown, and the plants grew. They were kept in the open air in a building erected for the purpose. The arrangement was such that the plants were exposed in the day-time in pleasant weather, but put under cover when it rained and at night. They had enough plant-food to enable them to make more or less growth independently of the nitrogen of the air, but were free to get the nitrogen from the air in case they were able to do so. They grew well. Many of them were as well or better developed than those in a rich garden-soil near by.

The amount of nitrogen in the seeds and in the nutritive solutions was determined by analyses at the beginning of the experiments. The same was done with the nitrogen in the plants at the end of the experiments, and with that left in the nutritive solutions. The quantities of nitrogen supplied to the plants at the beginning, and contained in them at the end, of the experiment were thus determined. The plants were found to contain more nitrogen than had been supplied by the nutritive solutions and the seeds. For this gain there was but one possible source, the atmosphere. The peas had in some way acquired nitrogen from the air, and in some cases the quantities of atmospheric nitrogen thus obtained were very large.

Since that time a number of investigators have obtained similar and even more striking results, and much light has been thrown upon the ways by which the plants are enabled to obtain the nitrogen from the air.

Professor Hellriegel in Germany has found from a large number of experiments that pea, lupine, and serradella plants obtain large quantities of nitrogen from the air, while oats, barley, and buckwheat seem to be restricted to that supplied to them in the soil and obtained through the roots. He has furthermore brought out the very important fact that there is a connection between the nitrogen acquired and the tubercles which are found on the roots of leguminous plants. The root-tubercles are the bulb-like enlargements, from the size of a pin-head to that of a pea or larger, sometimes called "warts," which are found on the roots of beans, peas, clover, cow-peas, and other leguminous plants. They are often thought by persons not botanists to be indications of disease. This suggests that minute organisms, termed "microbes," which are in some way connected with these tubercles, may be the agents by which the plants obtain nitrogen from the air.

To test the influence of the microbes in the soil, Professor Hellriegel prepared soil-infusions by putting small quantities of soil in water, shaking the mixture thoroughly, and letting it settle. The water was then assumed to contain the microbes. The infusions thus prepared were put into the sand in which the plants grew. In a very remarkable series of trials it was found that where leguminous plants were supplied with mineral but no nitrogenous food, and received these infusions, they grew well, had tubercles upon their roots, and contained large quantities of nitrogen when mature. Those which received no infusions, or infusions which had been sterilized, i.e., in which the microbes had been killed, made very little growth, had few or no tubercles, and showed no gain of nitrogen. In another experiment Professor Hellriegel grew peas and buckwheat inside a large glass globe, as Boussingault had done, except that soil-infusions were added. In both Hellriegel's and Boussingault's experiments the plants had practically no nitrogen except that in the seed and the free nitrogen of the air. Boussingault's plants made very little growth, and showed no gain of nitrogen. The same was true of Hellriegel's buckwheat; but his peas grew well, and gained considerable nitrogen. In other words, where the microbes were present, the peas evidently utilized the free nitrogen of the air.

Professor Wolff in Germany has reported experiments with clover which imply acquisition of atmospheric nitrogen. Numerous other late experiments indicate that both plants and soil obtain nitrogen from the air.

The experiments now described in this bulletin may be divided

into the following series: 1888, Champion of England peas, 25 trials; 1888-89, alfalfa, 5; 1889, East Hartford Early peas, first series, 33; 1889, Champion of England peas, 16; 1889, oats, 10. Other series with other plants are begun, but are not yet ready to be reported upon. The following questions were proposed for study: 1. May plants grown under normal conditions acquire any considerable amount of nitrogen, free or combined, from the surrounding atmosphere? 2. What effect has the addition of soil-infusions upon the formation of root-tubercles? 3. Is there a definite relation between the formation of root-tubercles and the acquisition of atmospheric nitrogen?

The method was essentially the same as in the previous experiments by Mr. Wood above described. The plants were grown in glass jars containing sand, purified by washing and igniting. Nutritive solutions, either free from or containing known quantities of combined nitrogen in the form of nitrate of potash or lime, were applied to the sand. The amounts of nitrogen supplied in nutritive solutions and seed were compared with the amounts found at the end of the experiments in residual solutions and plants. The difference between these two amounts must show the loss or gain in nitrogen. A loss must indicate decomposition of either the organic nitrogen of the seed or plants or the nitric acid of the nitrates fed, or both. A gain must represent the nitrogen acquired from the air in excess of any lost either from organic matter of seed or plant or from nitrate of the food.

The conditions of growth were varied by varying the amounts of nitrogen supplied in nutritive solutions. The minerals needed for the growth of the plants were added in amounts to make one part or less by weight of dissolved salts in one thousand parts of the solution. Some of the plants received no combined nitrogen except that in the seed; to others nitrates were added, but in such small quantities that the minerals were relatively in excess; to others enough nitrogen was added to make the mixture of plant-food correspond more nearly to the composition of the plants.

The answer to the question, "May plants grown under normal conditions acquire any considerable amount of nitrogen from the atmosphere?" coincides with the earlier experiments at Mansfield, and is plain and unmistakable. Peas of small, early variety (Early Hartford) planted in sand, with no nitrogenous food except that in the seed, grew to a height of over five feet. With nitrogen supplied in the solutions, they sometimes reached a height of over eight feet. Many of the peas and alfalfa plants accumulated large quantities of nitrogen from the air. In one case a single plant thus obtained more than one-third of a gram (54.6 grains) of nitrogen.

In a number of experiments with peas in which the roots had few or no tubercles, instead of gain, there was a decided loss of nitrogen. This gives added force to the suggestion that if nitrogen escaped in some of the trials, it may have escaped to some extent in other cases also. If so, the results are all inaccurate as indications of the actual atmospheric nitrogen acquired, and the plants must have really obtained more than the figures imply.

It may be that the loss of nitrogen is greater in some classes of plants than in others. The apparent loss in the experiments with peas was about as large when they were not fed combined nitrogen, other than that in the seed, as when they were fed considerable quantities of nitrates. In the experiment with oats the results were very different. Without the addition of nitrates, there was no loss, but a slight gain. When nitrates were fed, there was loss; and the larger the amount of nitrates added, the greater was the loss of nitrogen.

These experiments do not tell to what extent the loss observed with the oats, and with the peas which had no root-tubercles, was from the seed, and to what extent from the nitrates; whether, as seems most likely, it was due to the action of microbes; or what connection there may be between plants of different species and the loss of nitrogen. These and kindred questions must remain for future research to decide. But one can hardly help coupling this observation of the large loss of nitrogen in the oat experiments with the common observation of practical farmers that oats are an exhaustive crop. The power of leguminous plants to acquire nitrogen from the air evidently explains in part why they are such valuable "renovating crops."

Experiments by Berthelot and others imply that nitrogen is being continually gathered from the air by soils, and that microbes, and probably electricity, aid the process. A large amount of late research tends to show that nitrogen compounds in the soil are being constantly decomposed by the action of microbes, and that the nitrogen thus set free escapes into the air.

In Hellriegel's experiments the development of the root-tubercles on the plants seemed to be dependent upon the addition of soil-infusions: in those of the Storrs School Station, although the sand and water were sterilized, root-tubercles were often abundant where no soil-infusions were added. This was especially the case where the plants had some nitrogenous food. Indeed, where the plants were reasonably well fed, so far as the root-tubercles were concerned, it made no apparent difference whether they had soil-infusions or not; nor was there much difference where the plants had no nitrogen in their food. The plants were grown near a garden in which the soil was rich; and the microbes, which seem to be connected with the root-tubercles, were probably abundant. The most natural explanation is, that the organisms or their germs (spores) were floating in the air; found their way to the pots in which the plants were cultivated, and grew there; and that the growth of the microbes was especially favored where the plants had nitrates, i.e., had food enough to keep them vigorous until the tubercles were formed.

These experiments, like those of Hellriegel, reveal a remarkable relation between root-tubercles and the acquisition of nitrogen from the air by plants. Leguminous plants thus far experimented with have root-tubercles, and acquire atmospheric nitrogen. Other plants have been found to be without root-tubercles, and to gain little or no nitrogen; while in some experiments, as in those with oats, above cited, there is a large loss. There is an evident connection between root-tubercles and microbes, though the exact nature of the microbes and their connection with the tubercles remain to be explained.

While there is as yet no positive proof that the root-tubercles or the microbes are the cause of the gain of nitrogen, the fact that there is a connection between the root-tubercles and the amount of nitrogen acquired by the plants from the air is unmistakable. In every case, without exception, where there were no root-tubercles, there was loss of nitrogen; where there were "few" tubercles, there was sometimes a slight loss of nitrogen, at other times a slight gain; with a "fair number" of tubercles, there was a decided gain; where there was a "large number" of tubercles, the gain of nitrogen was very large.

It may be that this relation holds in fields as well as in pot-culture. The past season the station grew a half-acre of cow-peas, which yielded at the rate of about eight tons of green fodder per acre. In some ten different places in the field the roots were examined, and found to be covered with tubercles of large size. At one end of the field, where the yield was relatively light, the roots had less tubercles than elsewhere, and in general where the growth was heaviest the tubercles seemed to be most abundant.

As to whether the nitrogen which the plants obtain is the free or the combined nitrogen of the air, these experiments do not bring absolute proof, but the quantities of nitrogen obtained are so very large as to leave little doubt that it is free nitrogen; and the experiments of Hellriegel above cited would seem to prove that the uncombined nitrogen can thus be used. This and the cognate question as to how the nitrogen is acquired, demand further study. Investigations in this line are being planned for at the station.

This subject has a wider significance than what has been said above implies. The future welfare of our race, material, intellectual, and moral, depends upon the food-supply, or, in other words, upon the product of the soil. This, in turn, reduces itself essentially to a question of phosphoric acid, potash, and nitrogen. Enough of the first two for indefinite time to come is assured in the deposits of phosphates and potash salts already discovered, but the probability of a sufficient supply of nitrogen has been questioned. This costliest of the fertilizing elements escapes from our soils into the air and into the sea, and is taken away by crops, and not completely returned. Artificial fertilizers promise to meet but

a small fraction of the coming demand. If, as has been urged, the exhaustless stores of the atmosphere are not available to plants, the outlook is dark enough; but if the farmer may use his crops to gather it, without money and without price, we may dismiss our solicitude. With the assurance that plants obtain nitrogen from the air, the fear of starvation for the over-populated earth of the future may be ignored. That research is bringing the brighter answer to this problem, there seems to be most excellent ground to hope.

WARM AND COLD WATER FOR MILCH COWS IN WINTER.

WHETHER or not it is desirable in Wisconsin to warm water for domestic animals, has been experimented upon by F. H. King at the Agricultural Experiment Station at Madison.

On the night of Jan. 21, 1889, six cows were placed in stanchions side by side, in two groups of three each, upon a daily ration of five pounds of bran mixed with two pounds of ground oats and six pounds of hay, together with what dry cut corn-fodder they would eat up clean; and this ration was not changed until after the close of the experiment, March 25. During this time the cows were fed twice and watered once daily. They were allowed the freedom of the barnyard during the middle of each pleasant day, and in every way received similar treatment, except that, when one group of cows was getting water at 32° F., the other group took it at 70° F. The time of the experiment was divided into three periods of sixteen days each, having intervals between them. At the close of the first and second periods the temperatures of the water were reversed for each of the cows in order to eliminate, so far as might be, the individual differences of the two groups.

In plan this experiment contemplated as its chief object ascertaining whether it is true, as many farmers believe, that warm water for milch cows produces a measurable increase in the yield of milk over that of cold water, and, if so, whether this increase affected the volume simply, or the weight of the solids contained, to an extent which would make it remunerative in general practice to warm the water for cows.

The discussion of the results obtained has shown for these six cows, while under experiment, the following facts: —

1. While on warm water, they gave, on the average, 1.002 pounds of milk per cow per day more than while on cold water, or 6.23 per cent of the general average daily yield of 16.06 pounds.

2. They drank on the average, daily, while on cold water, 63 pounds; but while on warm, 73 pounds, or 10 pounds per cow more.

3. They ate more while on warm water than while on cold, and at the rate of .74 of a pound of corn-fodder per cow per day.

4. An increase in the amount of water drank was coincident with an increase in the quantity of milk given; and this was true irrespective of whether the water was warm or cold, an increase of 10 pounds in every 100 pounds of water drank being accompanied by an increase of 1 pound in every 100 pounds of milk given, nearly.

5. They consumed solid food, while on warm water, at the rate of 1.44 pounds for each pound of milk produced; and while on cold water, at the rate of 1.54 pounds for each pound of milk given.

6. An increase in the amount of water drank, when the temperature of the water remained the same, was associated with an increase in the amount of water in the milk without a notable increase in the total solids contained.

7. An increase in the temperature of the water drank, rather than an increase in the quantity of it, was associated with an increase in the total amount of solids produced.

8. There was a daily fluctuation in the percentage of water in the milk associated with a fluctuation in the amount of water drank.

9. Five cows manifested a strong preference for water at 70° over that of 32°, but one of the cows showed an even stronger liking for the iced water.

10. With but one exception, the cows, while they ate less and drank less during the cold-water periods, weighed more at their close, and, with but three exceptions, they weighed less at the close of the warm-water periods.

11. With butter at 20 cents per pound, skimmed milk at 25 cents per hundredweight, corn-fodder at $5 per ton, and the cost of warming water for forty cows 120 days at $15, the results obtained from the cows on the experiment indicate that a net gain of $21.36 would be realized on a herd of forty cows averaging sixteen pounds of milk per cow per day, and at least $10 on a herd of twenty, and $5 on a herd of ten cows. Counting corn-fodder at $10 per ton, the net gain on a herd of forty cows would still be $12.48.

THE ETHNOLOGICAL SIGNIFICANCE OF THE BEECH.

THE new science of linguistic paleontology has thrown a flood of light on several obscure problems of ethnology. It has, for instance, been proved that the names of the ass and the camel in Aryan languages are not primitive, but merely loan-words from the Semitic. This fact by itself goes far to disprove the hypothesis which placed the cradle of the Aryans in Central Asia, a region of which these animals are natives.

According to an article on the above subject by Canon Isaac Taylor, published in a recent number of *Knowledge*, in no case have more valuable results been obtained than in the case of the beech. This tree, which flourishes only in temperate climates, and is a lover of chalk subsoils, is confined to a definite and restricted area. It grows in the extreme south of Norway and Sweden, but is not found east of a line which strikes across Europe from the Frische Haff on the Baltic coast, near Königsberg, through Poland to the Crimea, ending finally in the Caucasus.

In former times the limit was more narrowly restricted. In Cæsar's time the beech had not reached Britain or Holland, while at the close of the bronze age, or the beginning of the iron age, it was only just beginning to replace the oak in Denmark. Early in the neolithic age its range was probably confined to France, northern Italy, and northern Greece; while in Germany, as Dr. Schrader believes, it did not extend north of the Thuringian forest. It flourishes in Macedonia, and clothes the north-eastern slopes of the Thessalian coast chain, while in the south of Epirus the ilex or evergreen oak replaces it as the characteristic forest-tree.

Within these ancient limits of the beech we must place the cradle of four Aryan languages, — German, Latin, Celtic, and Greek. We draw this conclusion from the following philological facts: the word for beech is, in Gothoic, *boka;* in Latin, *fagus;* in Celtic, *faidhbhile;* while the corresponding word, φηγός, denotes the oak in Greek.

With regard to other members of the Aryan family, the names for the beech — *buky* in old Slavonic, *bukas* in Lithuanian, and *buk* in Russian — are manifestly loan-words from the German. This would go to prove that the Slavs, in the prehistoric period, must have dwelt east of the beech line, though they have since advanced within it. Johannes Schmidt has shown reason for believing in the unbroken geographical continuity of the European Aryans, previous to the linguistic separation: hence they must be placed astride, so to speak, of the beech line, — the Slavs and Lithuanians in European Russia; and the Celts, Latins, Hellenes, and Teutons, farther to the west.

We have now to account for the fact that the word denoting the beech in Latin, German, and Celtic, has come in Greek to denote, not the beech, but the oak. A well-known explanation of the difficulty has been offered by Professor Max Müller in the second series of his lectures. He contends that the word originally denoted the oak, but that it was transferred to the beech at the time when the oak-forests of Jutland were replaced by beech-forests. But this does not account for the fact that the Latin word *fagus* means the beech, for Helbig has shown that the Umbrians had already reached Italy before the commencement of the age of bronze. The bronze age began in Italy earlier than in Denmark, and in the bronze age the oak was still the prevailing tree in Denmark, and was quite unknown in the neolithic age, when the Umbrians, whose language was a dialect of Latin, were already settled in Italy. The word *fagus*, therefore, must have denoted the beech in Latin at a period prior to the change in the forest-growth to